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VENTING AND BLOW-BY EFFECTS FOR THE MX TRENCH BASING MODE

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Two separate studies with simple models have been performed to study MX trench/plug venting and blow-by effects. By means of parameter variations many of the uncertainties in the in-trench blast environment were taken into account. In the first study it was found that the impulse loading on the blast plug was limited primarily by lack of containment of the trench pressures due to the light overburden and weak trench roof. In the second study it was found that a 10m long blast plug is sufficient to withstand expected blow-by effects.

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I INTRODUCTION

In the MX trench basing mode concept, blast plugs are employed in the trench to protect the transporter-erector-launcher from the severe environment resulting from nuclear attack on the trench as a line target. The protection offered by the plug is twofold: isolation from blast pressures as well as isolation from the hot, radioactive gaseous products of the nuclear detonation.

Two separate studies of these facets of the trench/plug system have been made. The purpose of the first study was to determine the blast loadings to which the plug would be subjected and for which it should be designed. In particular, the study shows the effectiveness of the light overburden and weak trench roof in allowing venting of the in-trench blast environment subsequent to its stagnation at the plug. In this manner, the trench design can limit the impulse loading on the blast plug.

The second study involves the possibility of leakage of upstream in-trench gases beyond the blast plug through the gap formed between the trench roof and the plug. The main result of this study is the determination of the minimum length of blast plug required to prevent such leakage under various circumstances.

2. VENTING OF TRENCH NEAR BLAST PLUG

This study involves the trench roof response in the vicinity of the blast plug for the MX trench baseline configuration. The region of computation for this study is shown in Fig. 1. The Brode overpressure surface loading (Reference 1) together with the upstream boundary conditions constitute the forcing functions for the analysis. The upstream in-trench input is constructed on the basis of results obtained from other groups who are studying the problem closer to ground zero. This input can be applied in either of two ways: (a) on a Lagrangian boundary or (b) on an Eulerian boundary. In the results presented here only option (a) has been used with an applied boundary pressure.

The action of the trench roof and overburden is modeled simply, as shown in Fig. 2. The initial rest configuration can be transformed into either the venting mode or the collapse mode, as required by the flow conditions in the trench. (It should be pointed out that the parameter β, which appears for the venting mode, merely aids in characterizing the area through which venting occurs. It is not necessary to assume the venting configuration shown in Fig. 2 to derive the equations used for venting.)

The governing equations in the analysis consist of the equation of motion of the air in the trench,

$$\rho\left(\frac{\partial u}{\partial t} + u\,\frac{\partial u}{\partial x}\right) = -\,\frac{\partial p}{\partial x}$$

the equation of state of the air

$$p = (\gamma - 1)\,\rho e$$

the energy equation,

$$\rho\left(\frac{\partial e}{\partial t} + u\,\frac{\partial e}{\partial x}\right) = -p\,\frac{\partial u}{\partial x}$$

and the continuity equation

$$\frac{\partial \rho}{\partial t} + u\,\frac{\partial \rho}{\partial x} = -\rho\left(\frac{\partial u}{\partial x} + \frac{Y}{A}\right)$$

In the above equations x is the (Eulerian) spatial coordinate, t is time, ρ, p, u and e are the density, pressure, velocity and specific internal energy of the air in the trench, respectively, and γ is a constant (equal to 1.4 in all the calculations reported here). The quantities Y and A are related to the motion of the trench roof through

$$A(t) = \begin{cases} \pi a^2 + 2\ as\ (t)\ \sin\alpha & \text{for } s \geq 0 \\ \pi a^2 + 2\ as\ (t)\ \sin\delta & \text{for } s < 0 \end{cases}$$

$$Y(t) = \begin{cases} [\dot{A} + v(s-d)\sin\beta] & \text{for } s \geq d \\ \dot{A} & \text{for } s < d \end{cases}$$

in which s is the upward displacement of the trench roof and overburden, a is the trench radius, α, β, and δ are fixed parameters defined in Fig. 2, v is the average velocity of air passing through the vent area, and d defines the minimum displacement at which a free venting path is formed. The venting is assumed to be Fanning, (frictional, steady, uniform-area) flow, i.e.,

$$v = \sqrt{(p - p_o)(s-d)\sin\beta\cos\beta/f\rho h} \quad \text{for } s \geq d$$

in which p_o is the Brode overpressure at any space-time point, f is the venting flow friction factor, and h is the overburden depth as defined in Fig. 2. If the trench roof clears the ground surface, $s \geq h$, complete venting is assumed, i.e. $p = p_o$.

The roof displacement s satisfies the equation of motion

$$\ddot{s} = [(p - p_o)\ell + \sigma h]/\rho_s \ell h$$

in which ρ_s is the soil overburden density, ℓ is given by

$$\ell = \begin{cases} 2\ a \sin \alpha \text{ if } s > 0 \\ 2\ a \sin \delta \text{ if } s \leq 0 \end{cases}$$

and σ is defined by

$$\sigma = \begin{cases} -\rho_s \ell g \text{ if } s > 0 \\ 0 \text{ if } s \leq 0 \text{ and } \dot{s} = 0 \\ \tau_s \text{ if } s \leq 0 \text{ and } \dot{s} < 0 \\ -\tau_s \text{ if } s \leq 0 \text{ and } s > 0 \end{cases}$$

where τ_s is the soil shear strength defined in Fig. 2 and g is the acceleration of gravity.

At the start of each computation the trench roof is stationary at its initial rest configuration and the air inside and outside the trench is at ambient conditions (assumed to be 10° C and 1 bar). The Brode load and/or upstream boundary input is then applied and the resulting flow allowed to impinge on the blast plug (which is assumed to be rigid). In the computations reported here, the in-trench inputs were constructed on the basis of information obtained from System, Science and Software (S^3) and Physics International (PI) for the case of a one megaton, on-line, surface burst 550 meters away from the plug. A total of three inputs, applied at a range 100 meters upstream of the blast plug were constructed on the basis of the following studies:

S^3 - No loss

S^3 - Expansion and ablation

PI - Expansion and venting

A baseline set of model parameters values, given in Table I, was assumed for this study. For these values, computations were performed for the three boundary inputs. In addition, because venting was found to be very important in determining the plug loads, the parameters associated with venting were varied as indicated in Table I, and computations using the new values (updating them one at a time) were run for the case of the S^3 expansion and ablation input.

TABLE I

VENTING AND COLLAPSE MODEL PARAMETERS

PARAMETER	BASELINE VALUE	VARIATIONS
a	2.5m	-
α	55°	-
β	45°	0°
δ	45°	-
d	0m	1m
f	0.01	0.004,0.10
h	2m	-
ρ_s	2g/cc	-
τ_s	3 bar	-

3. RESULTS OF PLUG VENTING ANALYSIS

The results of the computational study are shown in the Appendix and summarized in Table II. The figures state the input used and values of the parameters β, δ, f, τ_s, d. Each computation is represented by three figures. The first of these figures shows the assumed upstream boundary input, the pressure on the blast plus (labelled "plug load") and the Brode overpressure at the plug. The second figure shows the impulse acting on the blast plug, and the temperature and density of the air near the plug. Finally, the third figure of each set shows the displacement and velocity of the trench roof and overburden.

The results indicate that only the venting mode of trench behavior is triggered in the situations studied here. The venting leads to a relative insensitivity of plug impulse to the various assumptions made. Although there exist great differences between the upstream inputs as a result of different post-detonation assumptions (Table II), the resulting plug impulse is relatively insensitive to these differences. It is significant that insensitivity is also exhibited when the venting parameter values are varied over large ranges. This implies that the plug impulse is not greatly dependent on the details of the venting process as described by this model.

The results of the computations show that the high stagnation pressures which arise when the flow impinges on the blast plug serve to lift the trench roof and overburden, quickly leading to breaching and venting of the high pressures in the trench. This effect appears to be a result of the small amount of overburden and the weakened trench roof. The venting serves to limit the time over which these pressures act and thereby limits the impulse to which the blast plug is subjected.

TABLE II

RESULTS OF PARAMETER STUDY

INPUT		VARIATION FROM BASELINE	PRESSURE ON PLUG (kb)	IMPULSE ON PLUG (Bar-sec)
PRES (kb)	DECAY (ms)			
0.15	200	NONE	1.2	13
1.5	25	NO LOSS INPUT (S^3)	7.2	22
1.5	5	EXPANSION INPUT (PI)	1	6
0.15	200	ZERO VENT ANGLE	1.3	19
0.15	200	LOW VENT FRICTION	1.2	11
0.15	200	HIGH VENT FRICTION	1.3	17
0.15	200	DELAYED VENTING	1.4	18

It should be noted that the computations probably overestimate the loading on the blast plug because the mitigating effects of ablation, wall protuberances, wall friction and motion of the plug are all neglected in the region of computation.

4. BLOW-BY

As shown above, the high stagnation pressures on the blast plug will lift the trench immediately upstream of the plug due to expansion and venting effects. This in turn can lead to the situation depicted in Fig. 3 in which the overburden and trench roof directly above the blast plug are lifted to form a gap through which the hot gases upstream of the plug may leak. This situation has been termed "blow-by".

In order to estimate the magnitude of blow-by effects, the model shown in Fig. 3 was used. The trench and overburden are assumed to be at rest at the undisturbed (horizontal) position when, at $t=0$, the plug stagnation pressure p_o is uniformly applied to the trench roof upstream of the blast plug. After the initial pressure is applied, it is allowed to vary with time and axial position along the trench as a result of adiabatic expansion (until venting) of the gases in the trench. The venting is assumed to occur only after the trench roof and overburden have been displaced one full trench radius above the ground surface, i.e., $s = a + h$. This assumption of delayed venting is conservative because it leads to high in-trench pressures for lift-off at late times, thereby increasing the size of the blow-by gap. After venting is initiated the in-trench pressure decays exponentially with time with decay constant of t_v.

Two limiting geometries are considered to bound the lift-off process. These are axisymmetric and vertical. The former is valid at early times and represents the cylindrical expansion of the trench walls before the ground surface becomes important. The vertical lift-off is more representative of the situation at late times, especially during venting.

Finally, a composite material model is assumed to represent the trench roof and overburden. The material is assumed to be a von Mises material in shear with a failure strength τ_F and a shear modulus G. In compression the material is assumed to be perfectly locking, with a locking strain (porosity) of ε_o . In other words, point a in Fig. 3 is allowed to move upward while point b remains stationary until the compaction strain in the overburden is ε_o . Then points a and b move together as a rigid body.

The baseline set of model parameters is given in Tabel III together with variations assumed for the stagnation pressure in order to account for the large uncertainties in the in-trench environment.

TABLE III

BLOW-BY MODEL PARAMETERS

PARAMETER	BASELINE VALUE	VARIATIONS
P_o	1 kb	10 kb, 0.1 kb
t_{vo}	2 ms	-
τ_F	3 bars	-
ρ	2000 kg/m^3	-
G	300 m/s	-
ε_o	.05	-
a	2.5m	-
h	2.0m	-
D	10m	-

5. RESULTS OF BLOW-BY ANALYSIS

Six blow-by computations were performed, involving three values of the stagnation pressure P_o together with the two geometries of axisymmetric and vertical lift-off. The output consists of the gap formed as a function of time and locations along the length of the blast plug.

Typical results for the baseline calculations (P_o = 1 kb) are shown in Figs. 4a and 4b which show the blow-by gap plotted as a function of distance from the plug face at several times (which are given together with the corresponding in-trench pressure at that time). It can be seen that the large gaps formed near the plug face decay very rapidly along the length of the blast plug. At a distance of 6 m. there is essentially no gap formed.

Figure 5 shows the blow-by gaps as a function of distance along the blast plug for all six computations at a time when the in-trench pressure has fallen to 0.1 bar. Note that, because of impulse-momentum considerations, the lowest stagnation pressure results in the strongest blow-by effects. It can be seen in all cases that a 10m long blast plug will be sufficient to resist blow-by.

6. CONCLUSIONS

Two separate studies with simple models have been performed to study MX trench/plug venting and blow-by effects. By means of parameter variations many of the uncertainties in the in-trench blast environment were taken into account. In the first study it was found that the impulse loading on the blast plug was limited primarily by lack of containment of the trench pressures due to the light overburden and weak trench roof. In the second study it was found that a 10m long blast plug is sufficient to withstand expected blow-by effects.

REFERENCES

[1] Brode, H.L., "Height of Burst Effects at High Overpressure", DASA 2506, July 1970.

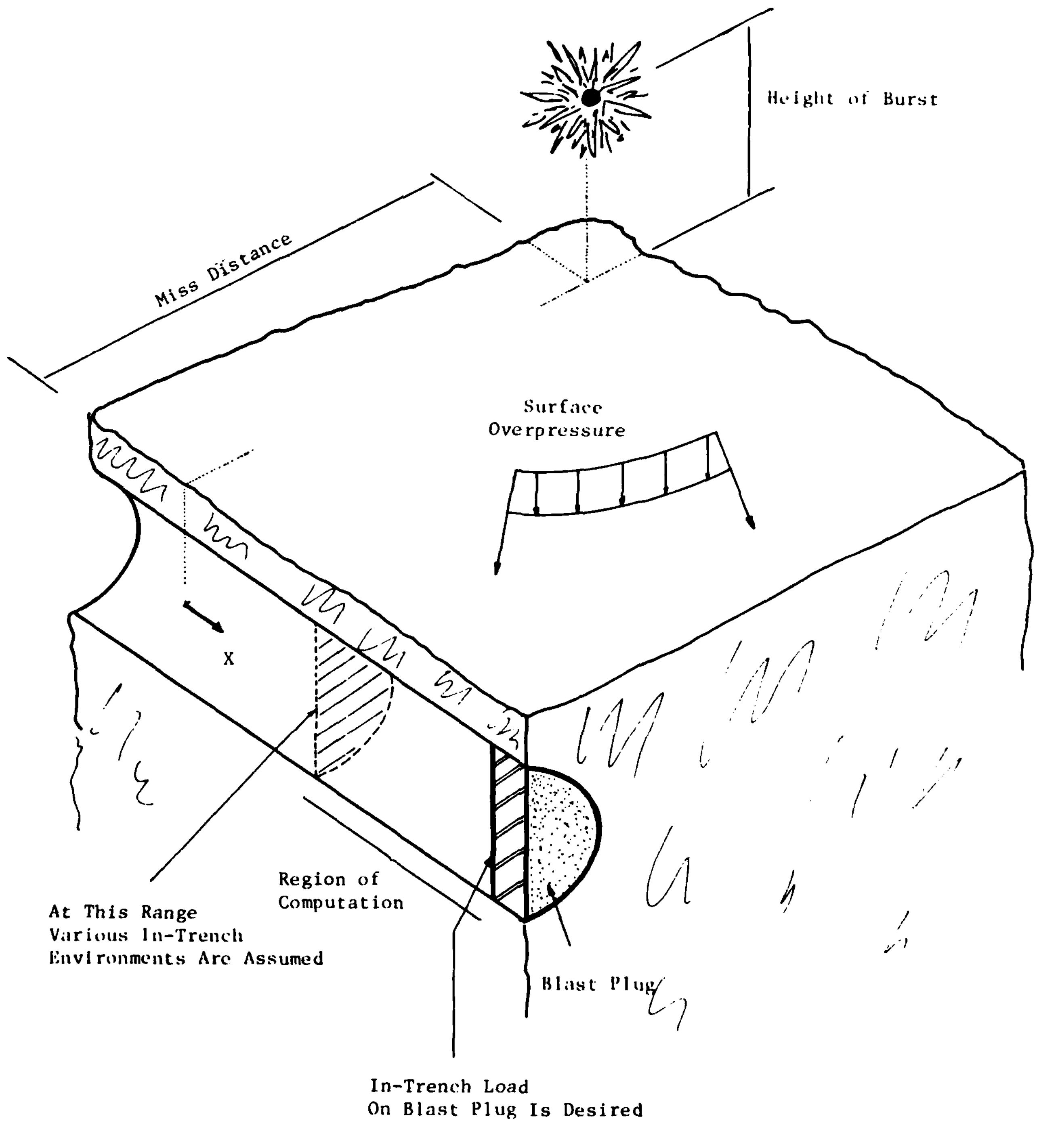
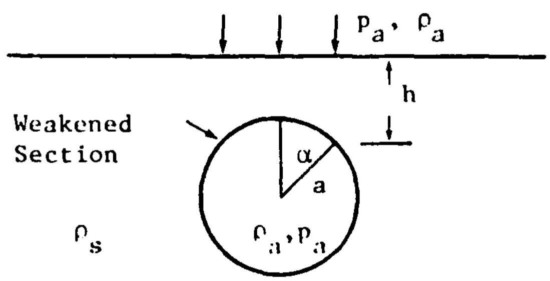
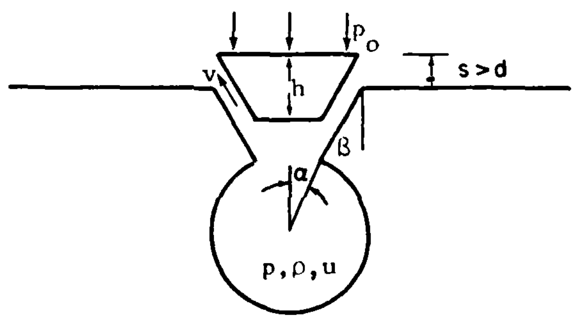


FIG. 1 MX IN-TRENCH ENVIRONMENT CONFIGURATION

1. Initial Rest Configuration



2. Venting Mode



3. Collapse Mode

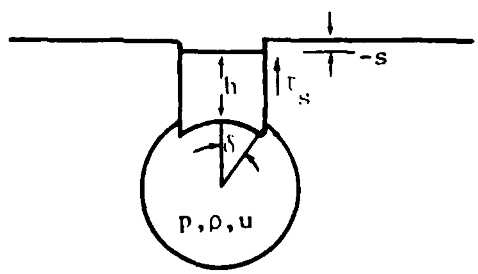


FIG. 2 COLLAPSE AND VENTING MODES OF TRENCH MODEL

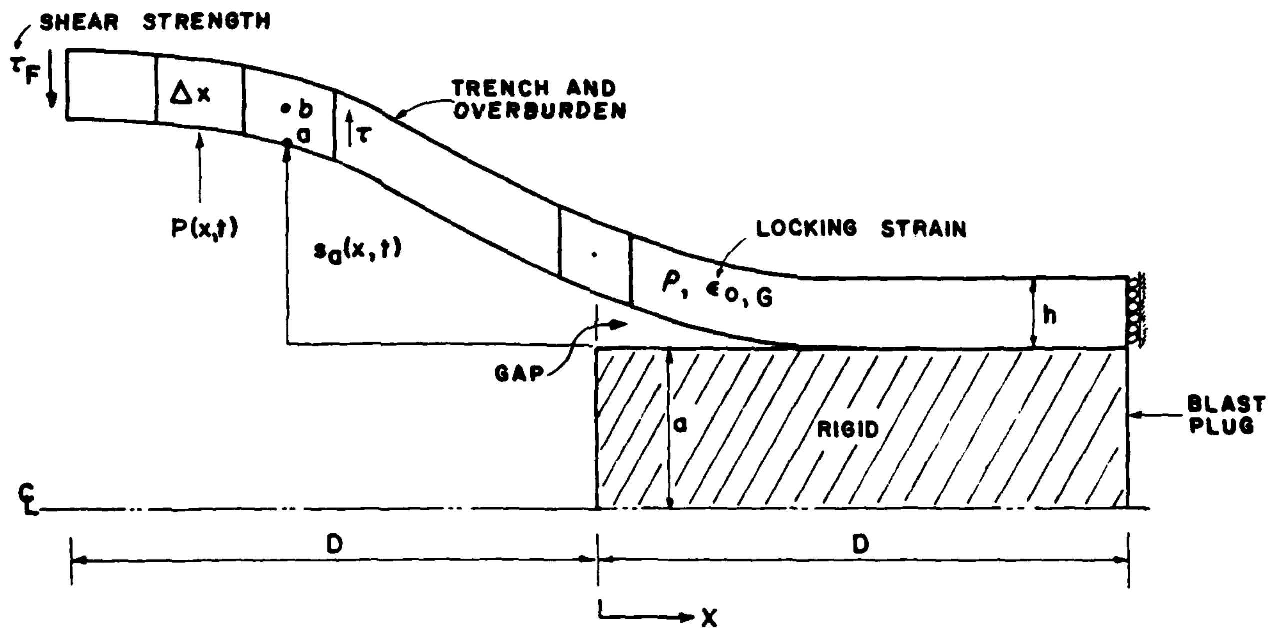
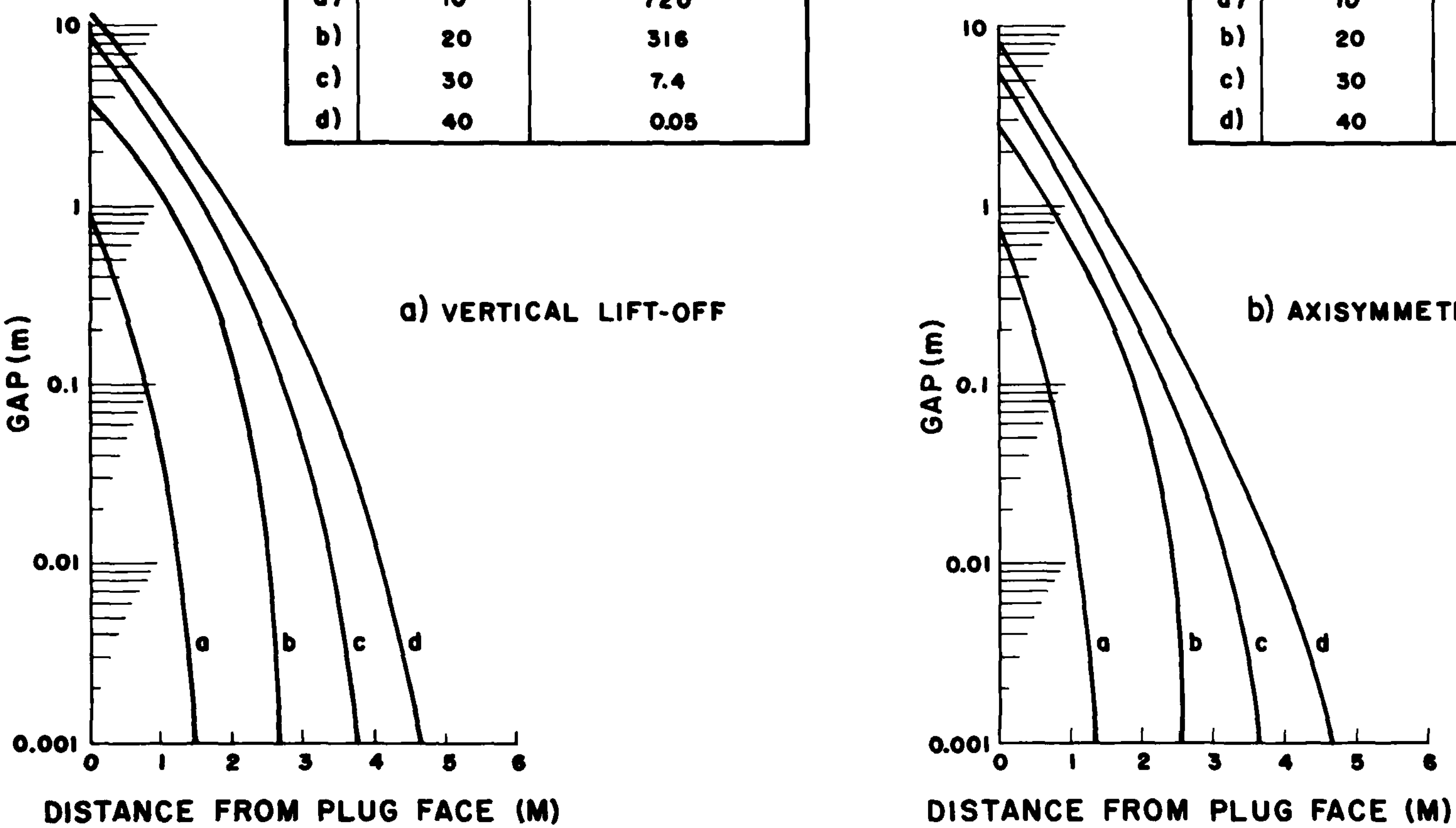


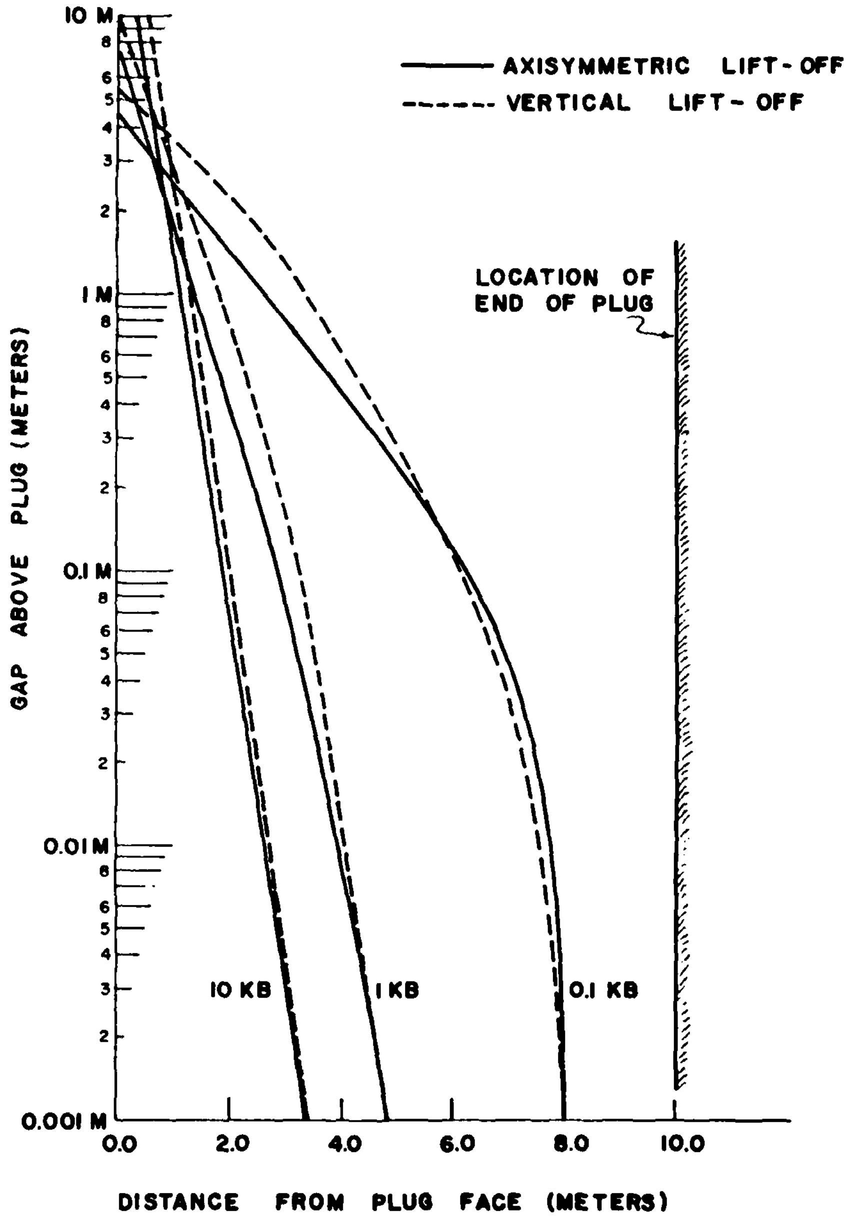
FIG. 3 MODEL OF TRENCH, OVERBURDEN AND BLAST PLUG FOR BLOW-BY ANALYSIS



	TIME (ms)	PRESSURE (bars)
a)	10	720
b)	20	316
c)	30	7.4
d)	40	0.05

	TIME (ms)	PRESSURE (bars)
a)	10	555
b)	20	142
c)	30	13,4
d)	40	0,09

FIG. 4 BLOW-BY RESULTS BASELINE CASE (P_o = 1 Kb)



BLOW-BY GAPS VS. DISTANCE FROM PLUG FACE FOR VARIOUS STAGNATION PRESSURES (AT TIME WHEN IN TRENCH PRESSURE IS 0.1 BAR)

FIG. 5

APPENDIX

Computational results for the MX Trench blast plug loading and the trench roof and overburden response in the vicinity of the plug.

IMP $\equiv$ Impulse on plug

TMP $\equiv$ Temperature of air at plug

DAIR $\equiv$ Density of air at plug

<u>*Note:*</u> The factors on the curves labeled "TMP", "DAIR" and "ROOF D", and on the axis labels for the plots in this appendix are to be multiplied by the numbers shown on the axes. As an example, the point labeled "1.00" on the axis marked "TIME (MS) x 10^2" represents a time of 1.00×10^2 ms, or 100 ms. Further, the ordinate "1.00" on the axis labeled "x 10^4" for the curve listed as "DAIR (kg/m^3) x .01" represents an air density of $1.00 \times 10^4 \times .01$ kg/m^3 = 100 kg/m^3.

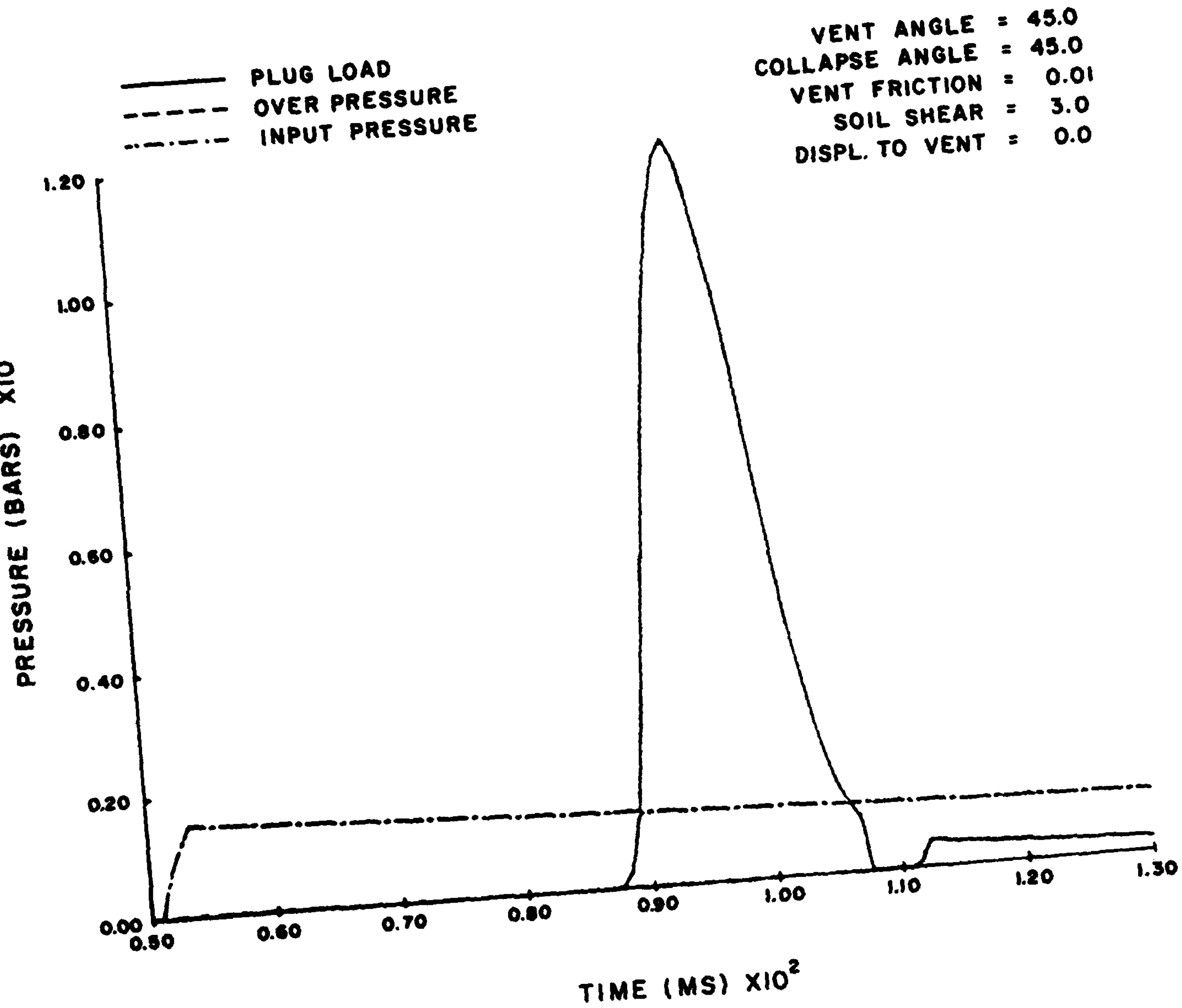


FIG. A-1a VENTING ANALYSIS - S^3 EXPANSION ABLATION INPUT (BASELINE)

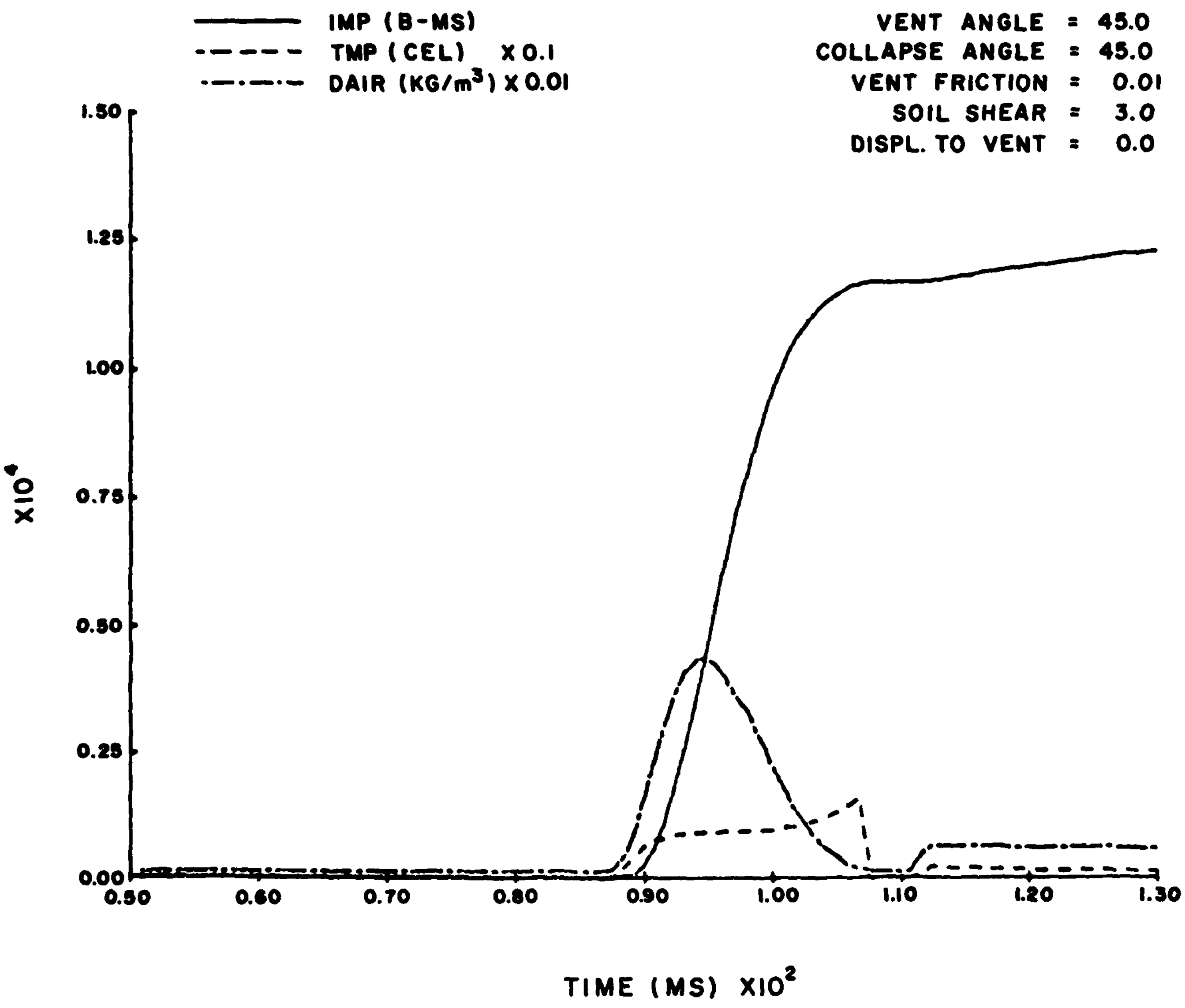


FIG. A-1b VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (BASELINE)

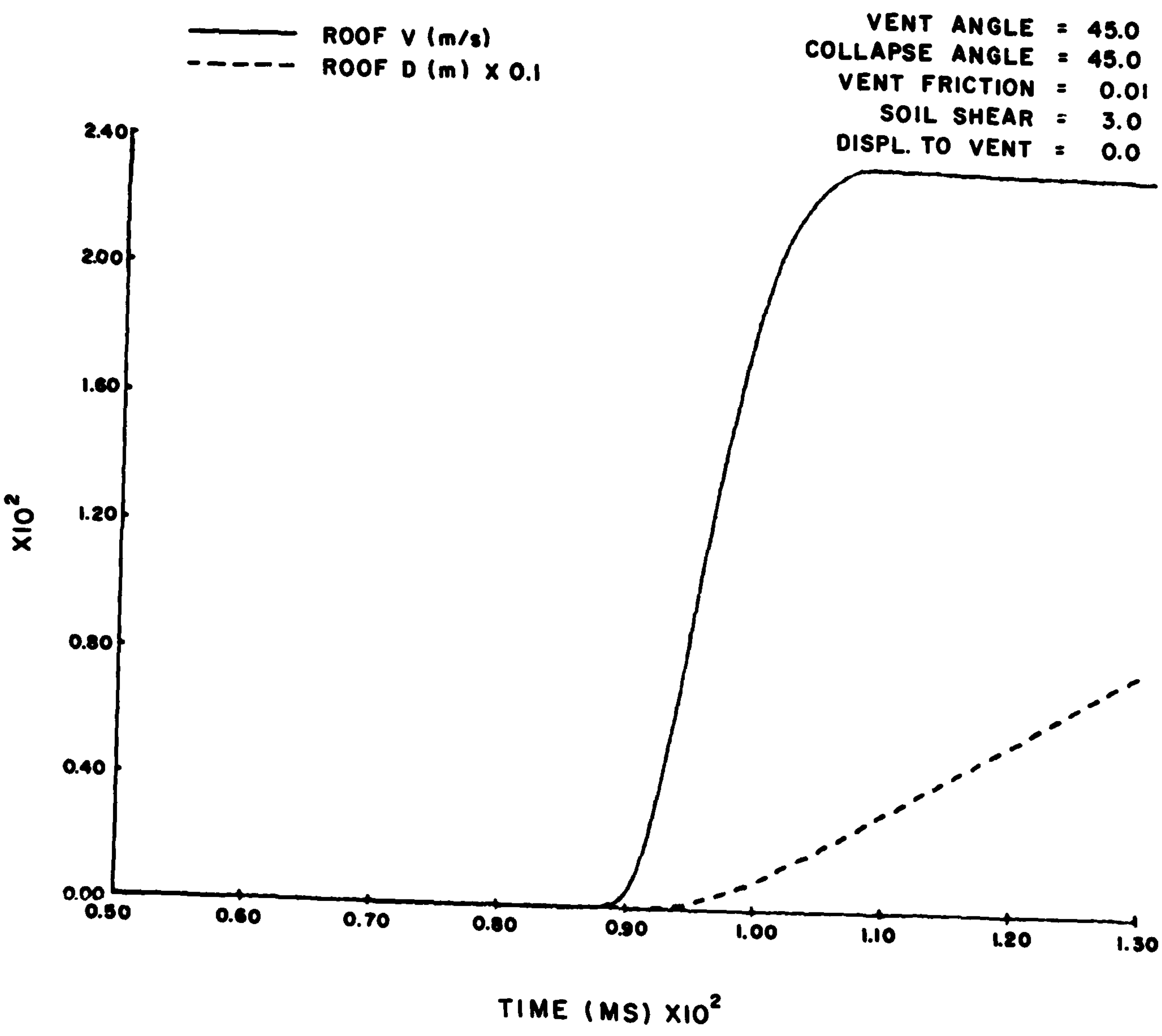


FIG. A-1c VENTING ANALYSIS - S^3 EXPANSION ABLATION INPUT (BASELINE)

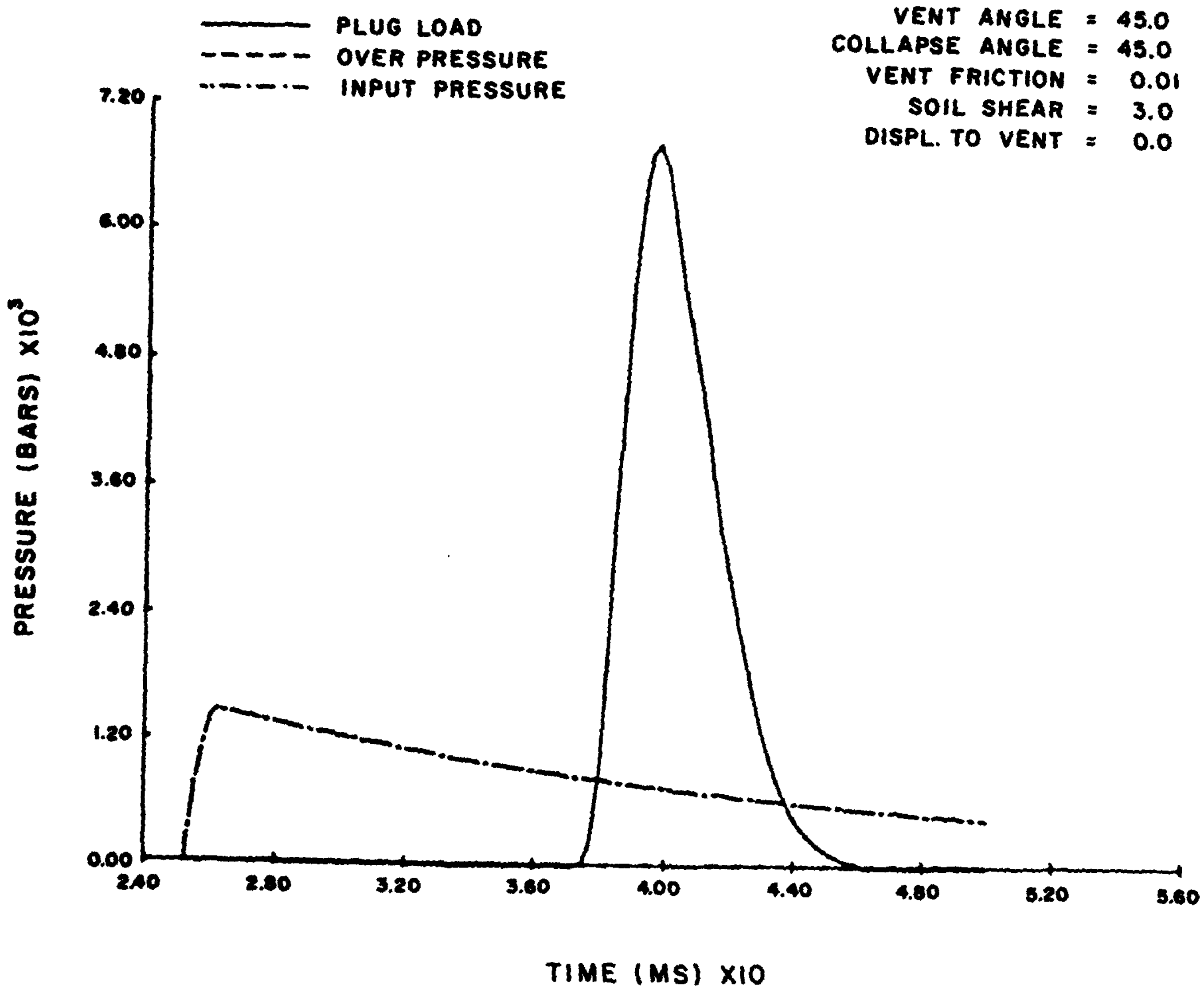


FIG. A-2a VENTING ANALYSIS - S^3 NO LOSS INPUT

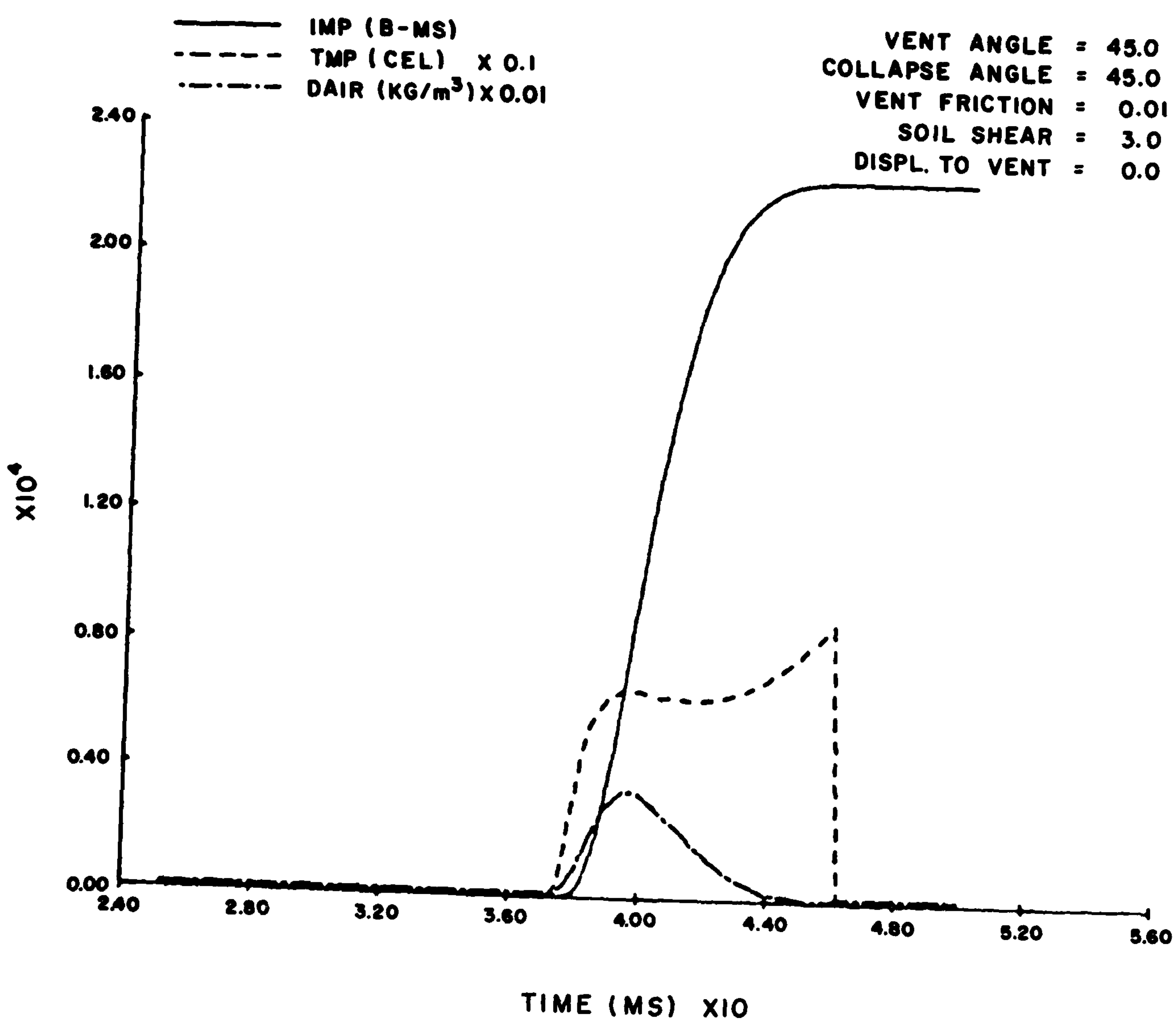


FIG. A-2b VENTING ANALYSIS - S^3 NO LOSS INPUT

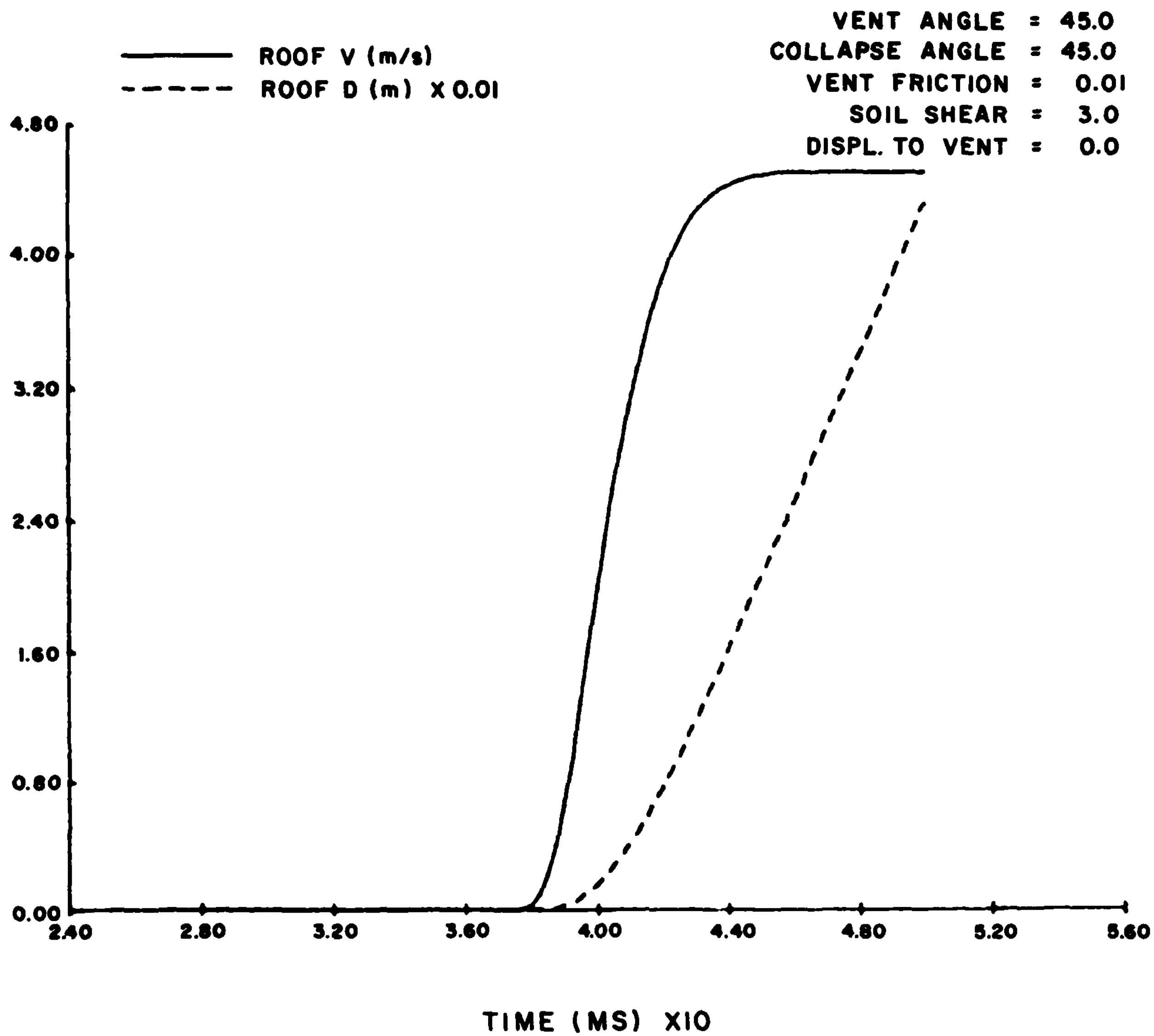


FIG. A-2c VENTING ANALYSIS - S^3 NO LOSS INPUT

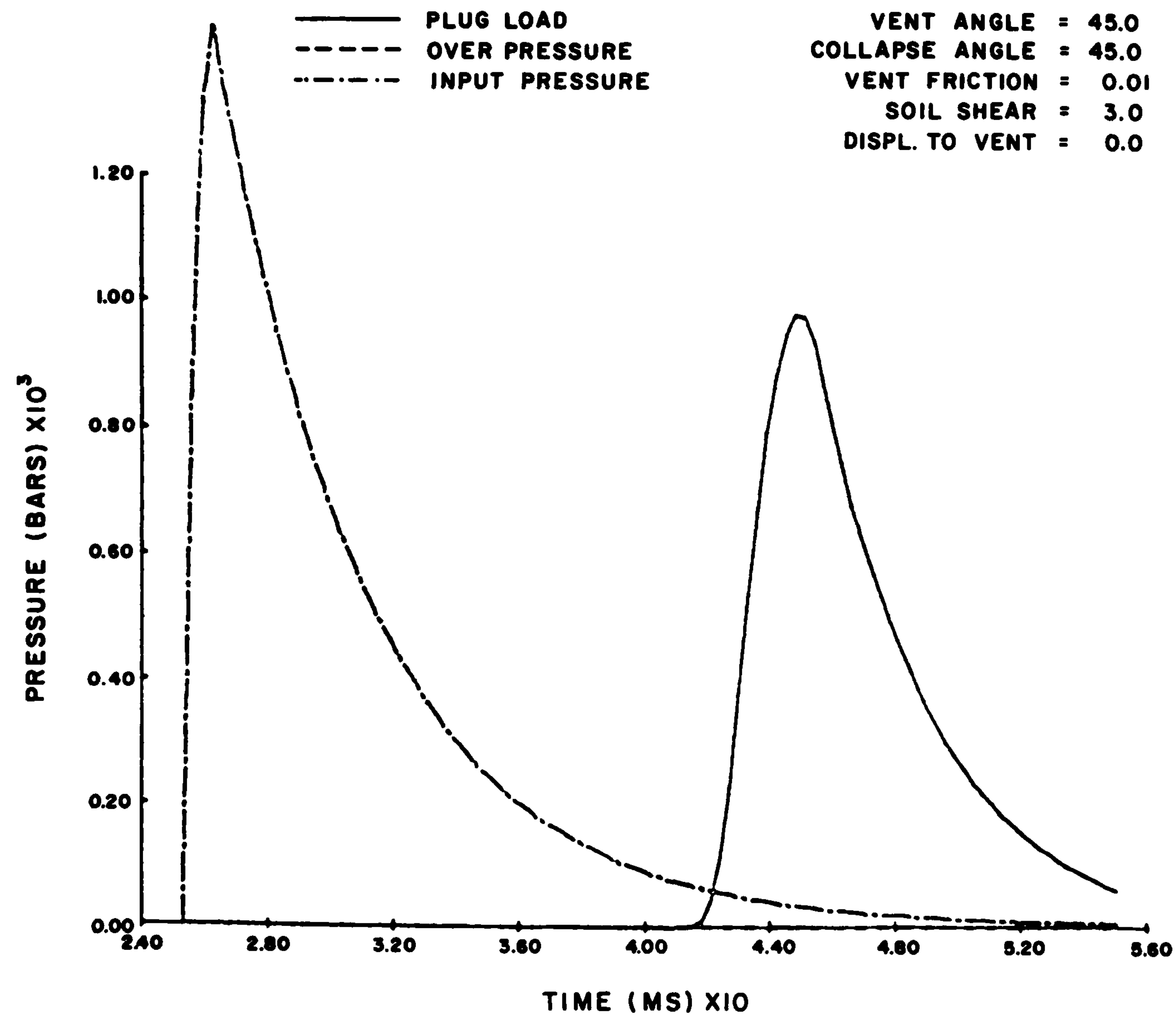


FIG. A-3a VENTING ANALYSIS - P. I. INPUT

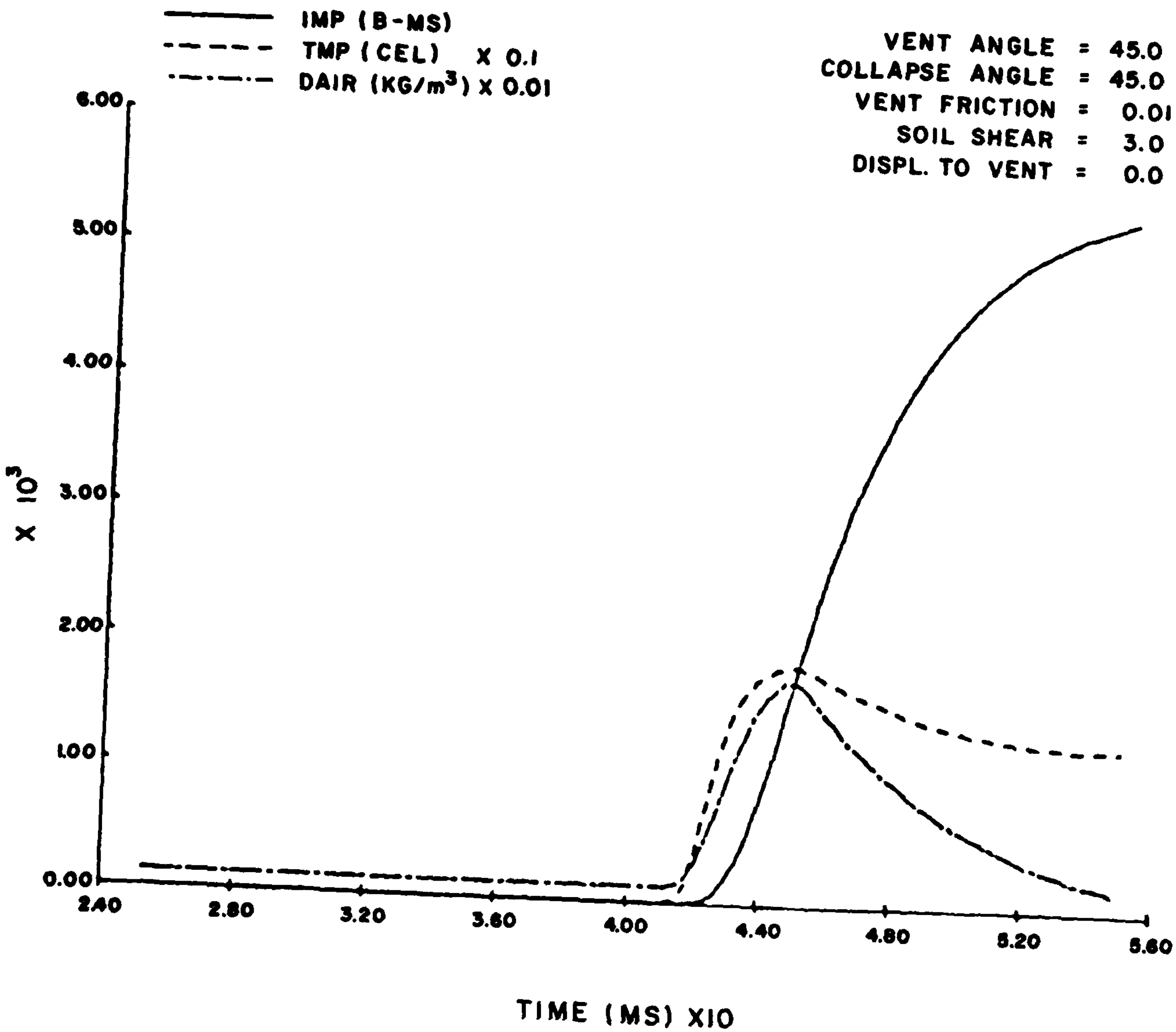


FIG. A-3b VENTING ANALYSIS - P. I. INPUT

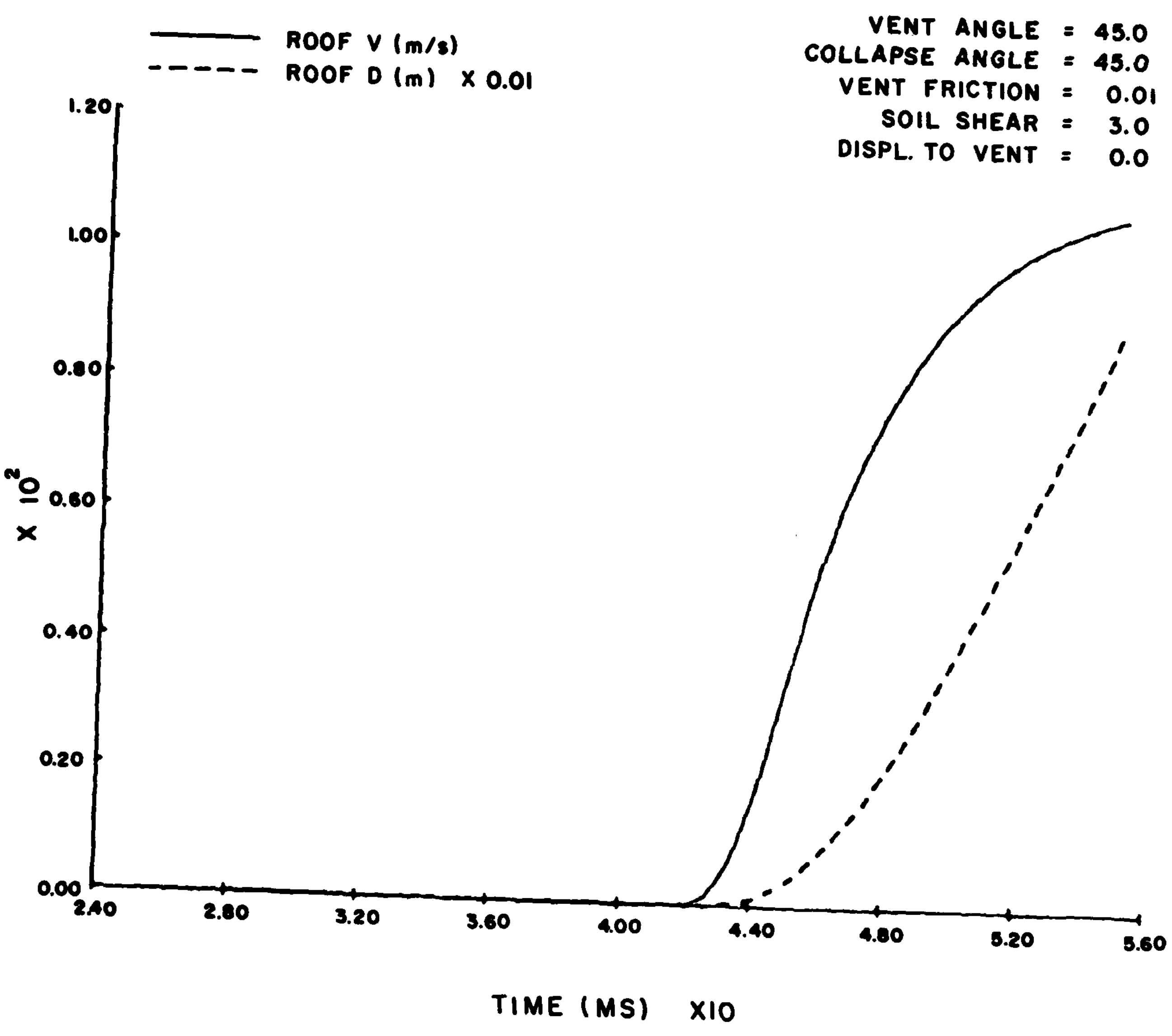


FIG. A-3c: VENTING ANALYSIS - P. I. INPUT

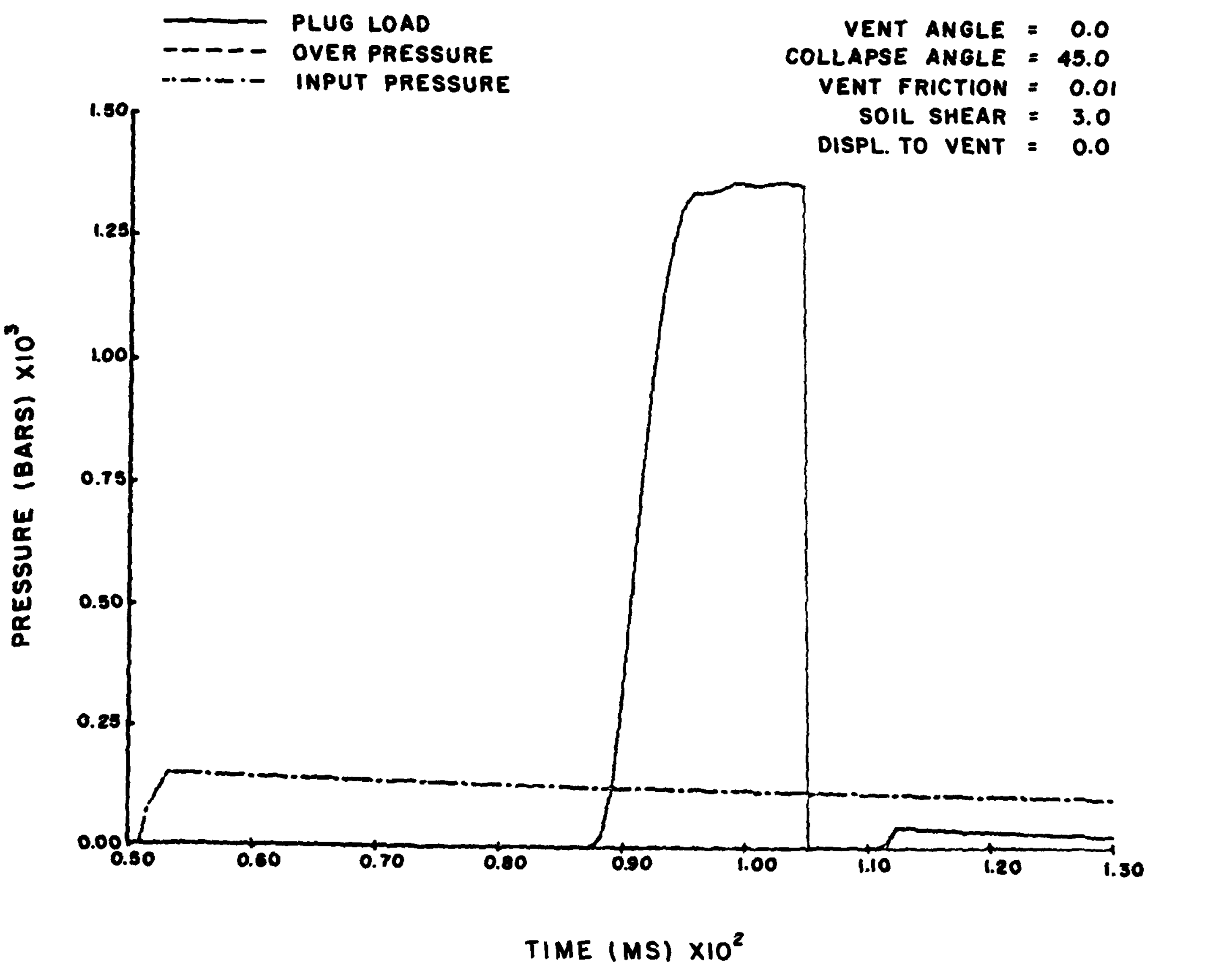


FIG. A-4a VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (0° VENT ANGLE)

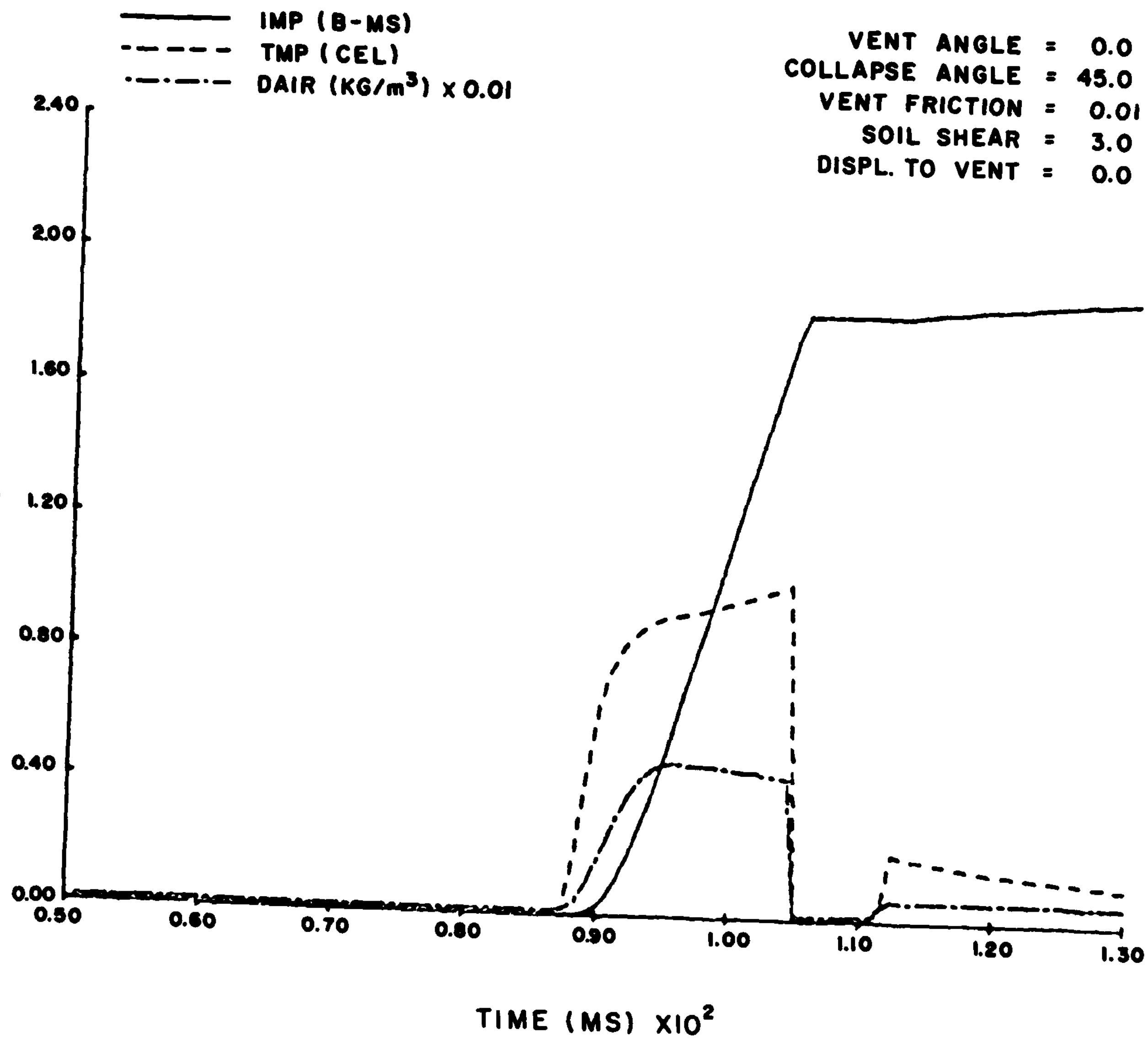


FIG. A-4b. VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (0° VENT ANGLE)

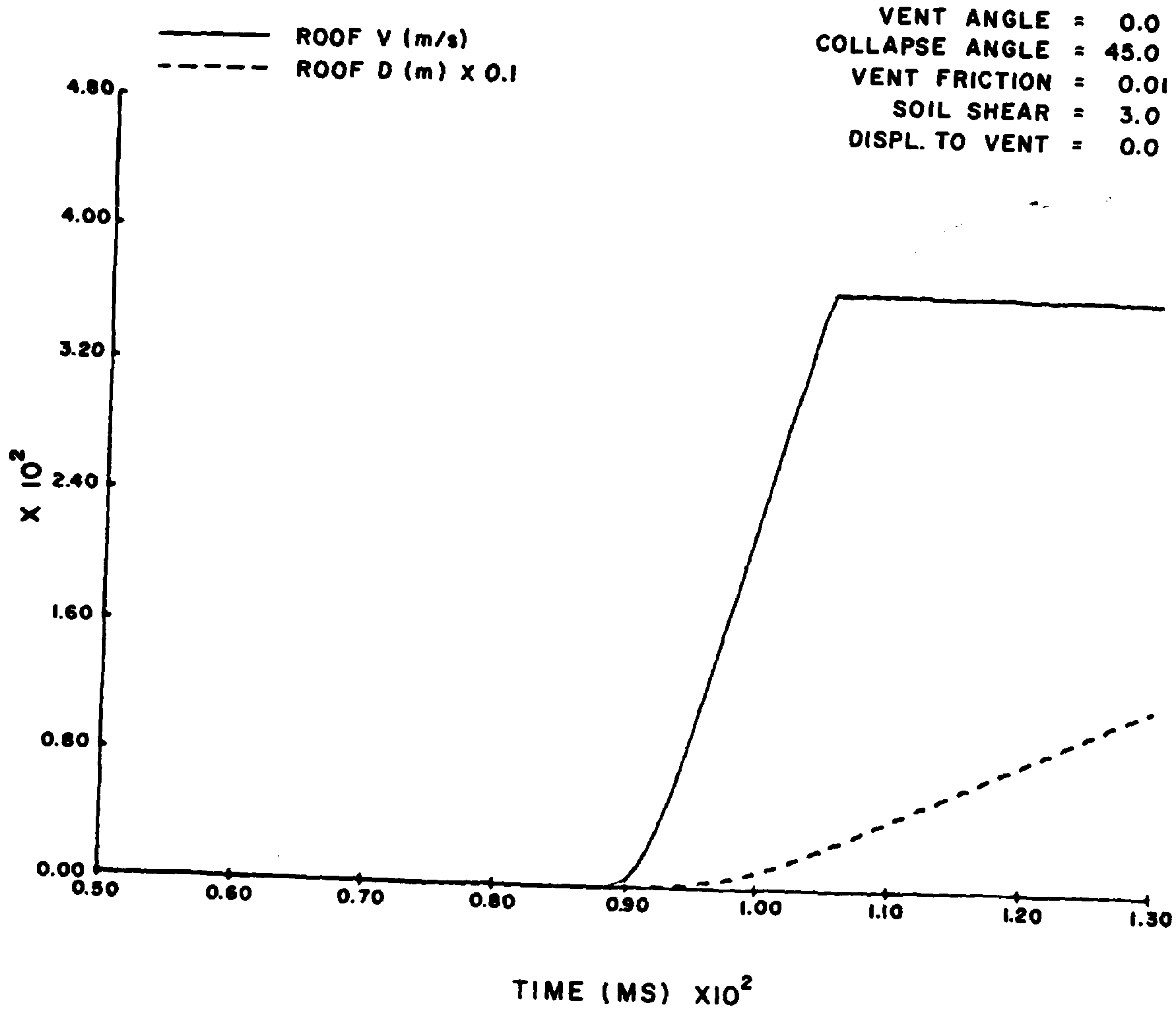


FIG. A-4c. VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (0° VENT ANGLE)

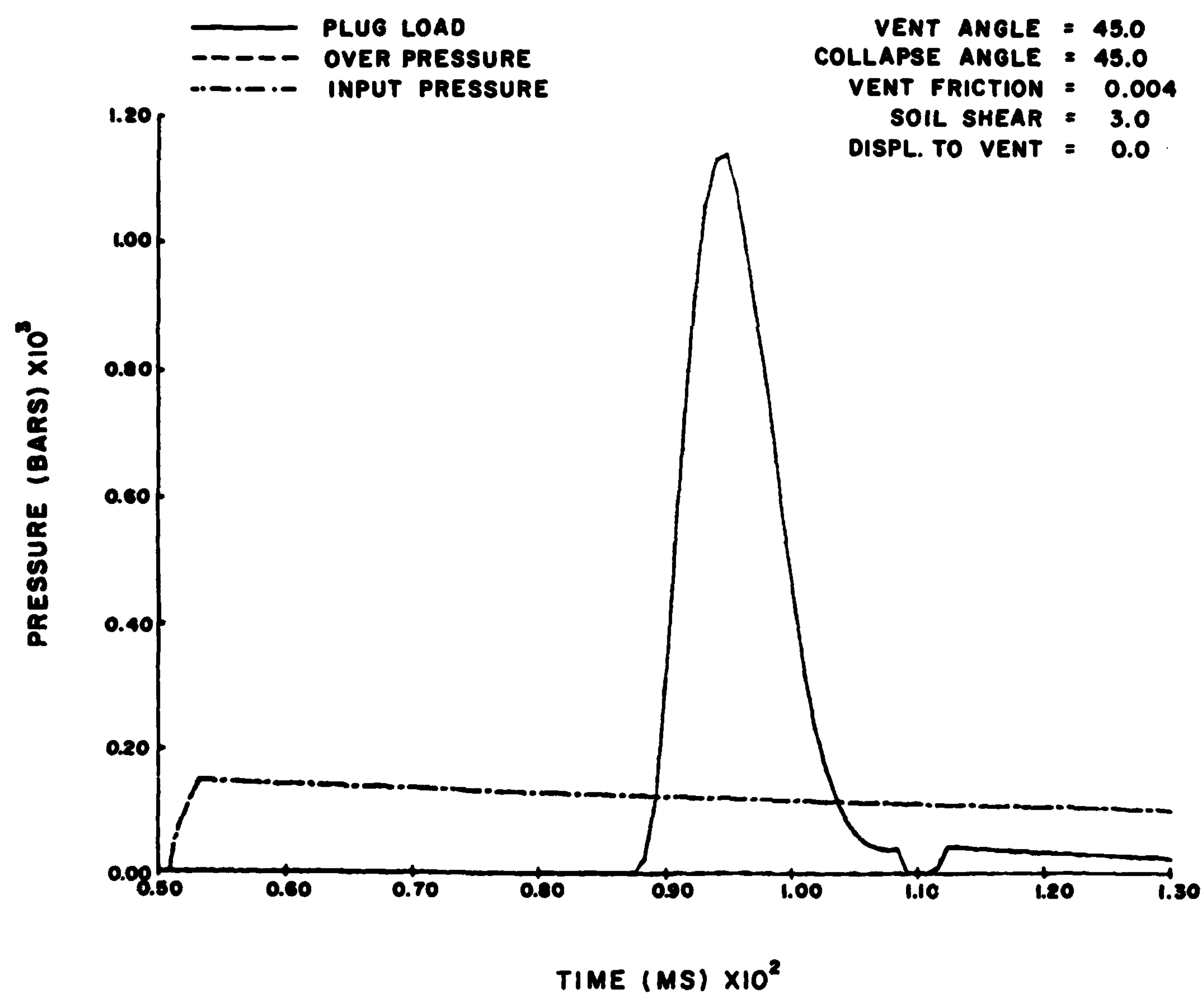


FIG. A-5a VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (0.004 VENT FRICTION FACTOR)

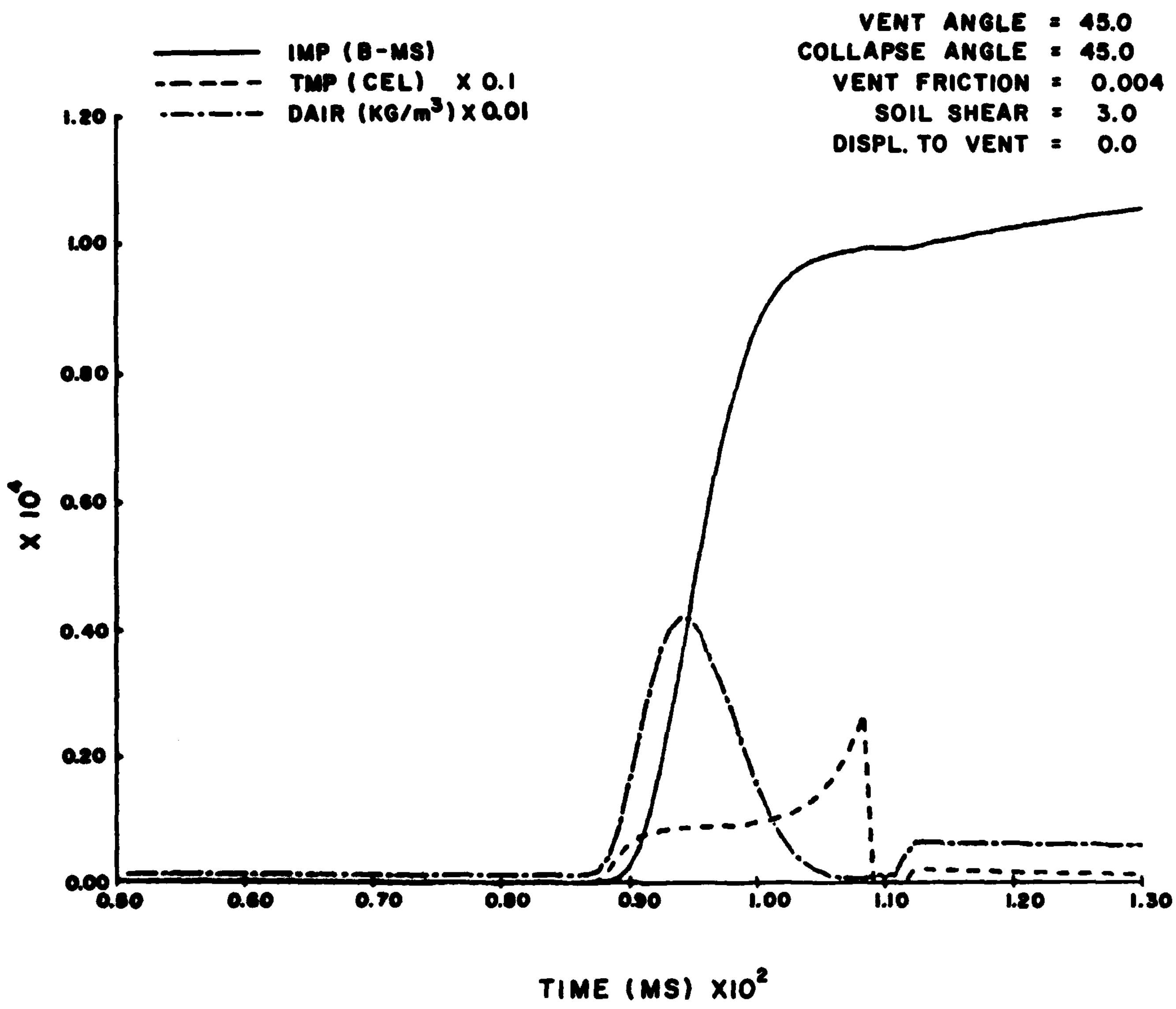


FIG. A-5b VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (0.004 VENT FRICTION FACTOR)

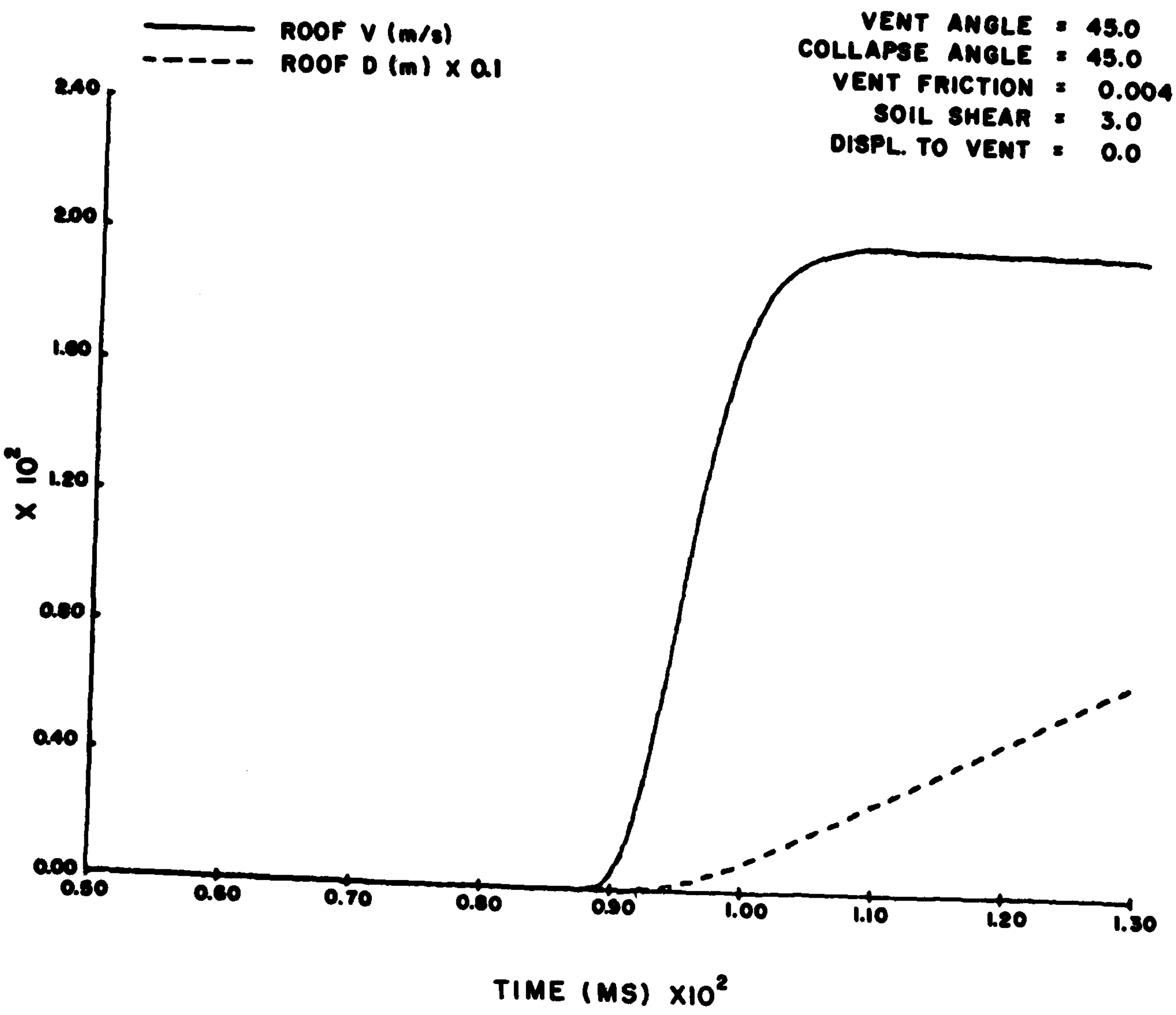


FIG. A-5c VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (0.004 VENT FRICTION FACTOR)

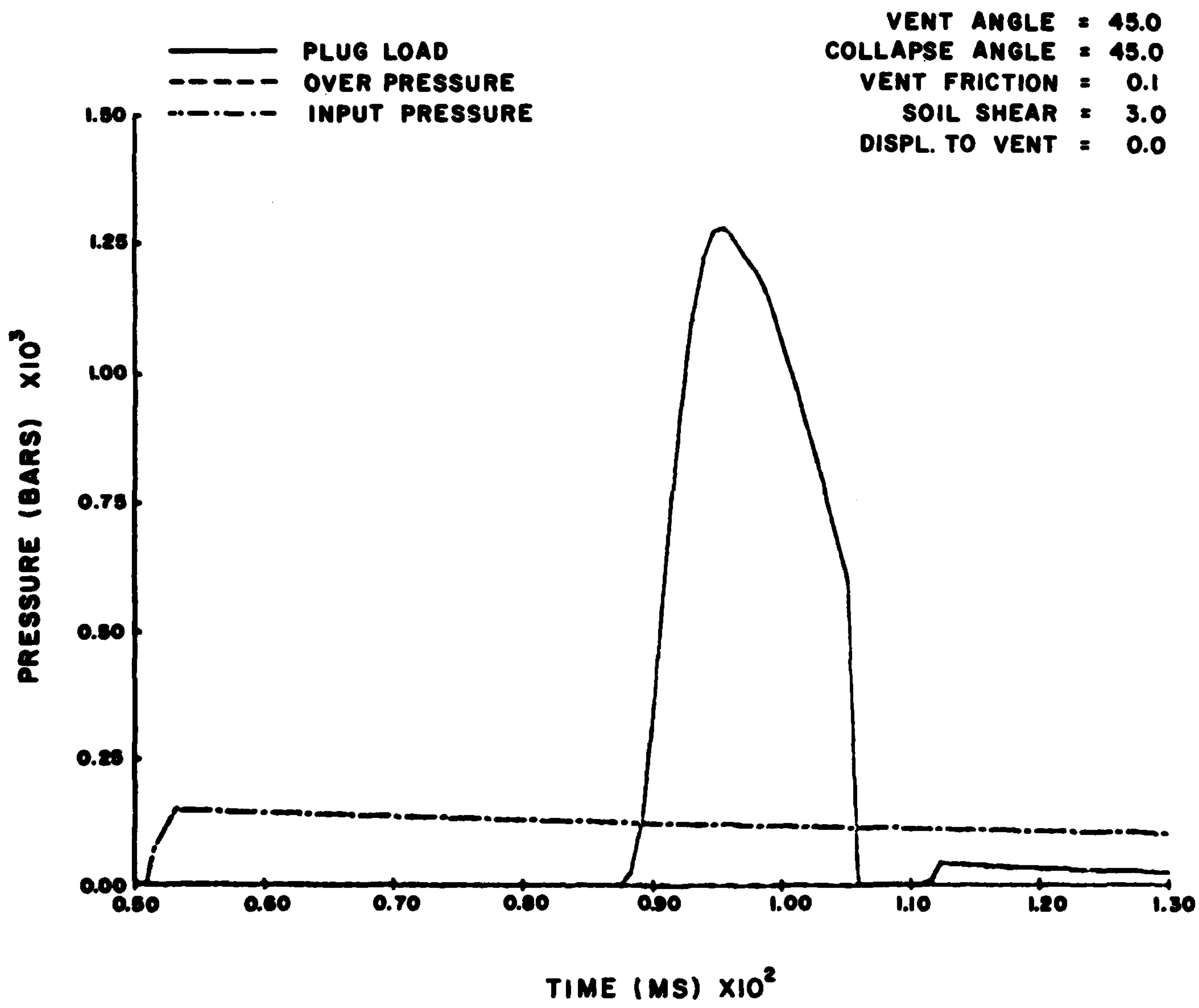


FIG. A-6a VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (0.1 VENT FRICTION FACTOR)

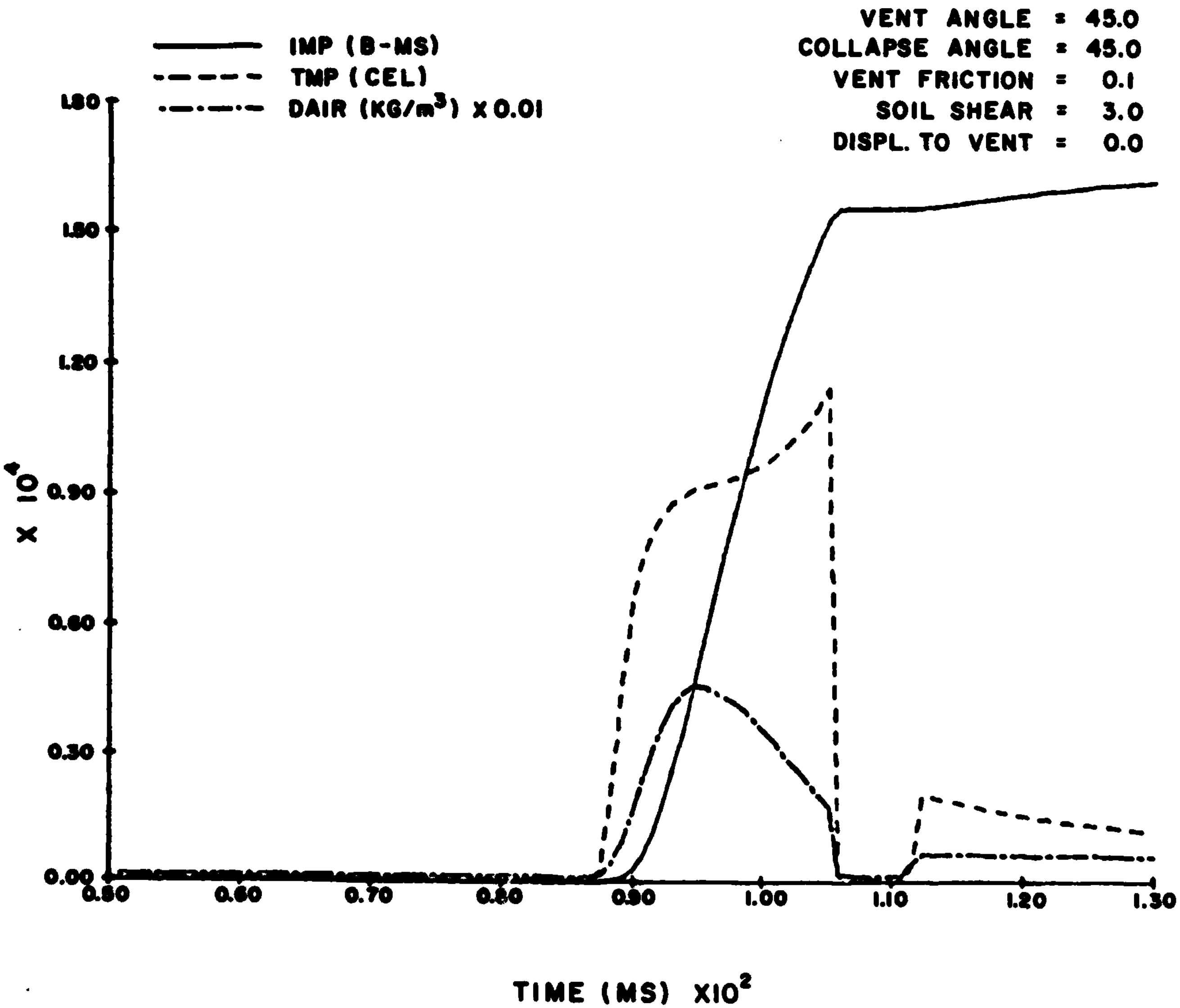


FIG. A-6b VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (0.1 VENT FRICTION FACTOR)

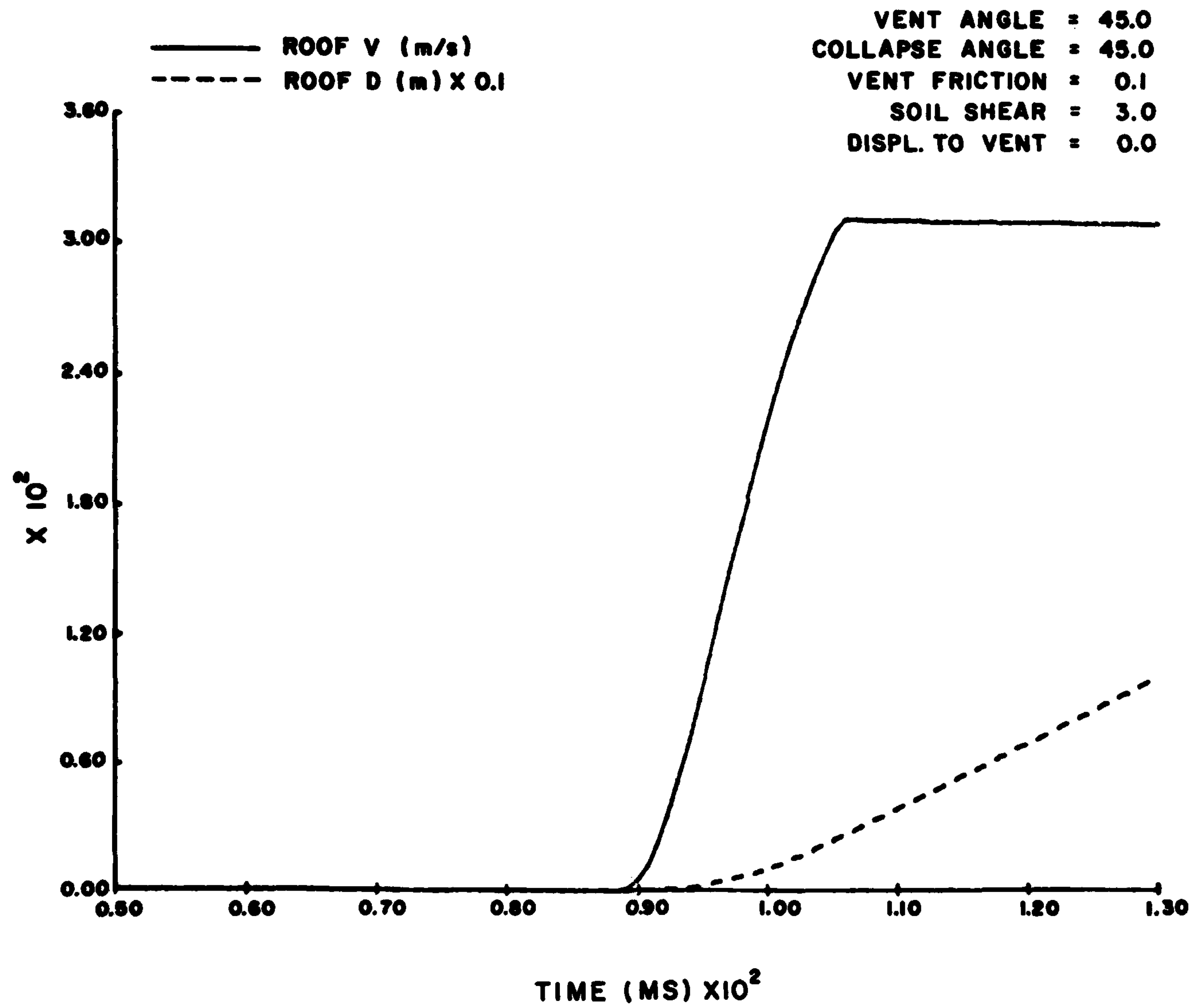


FIG. A-6c VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (0.1 VENT FRICTION FACTOR)

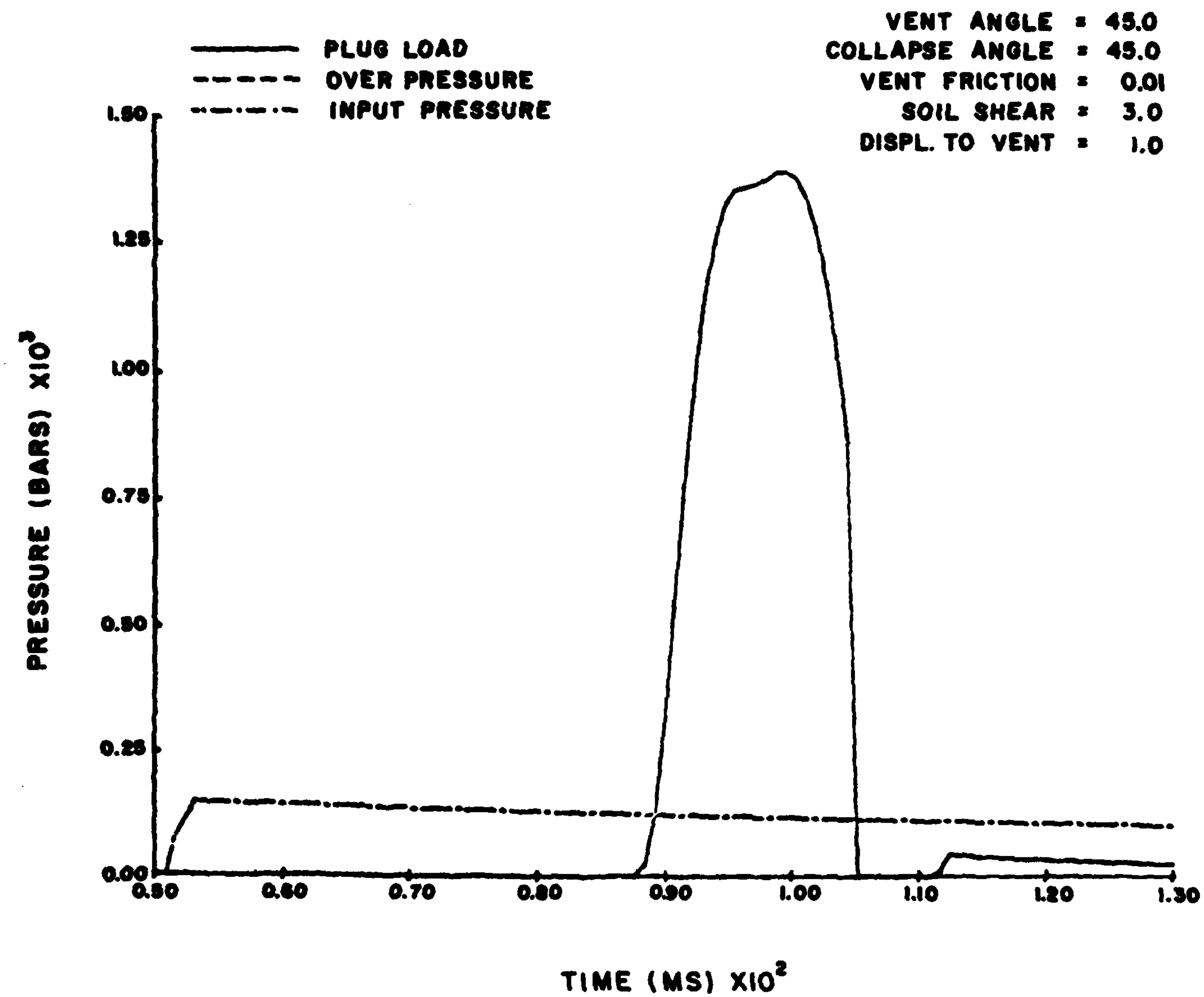


FIG. A-7a VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (1m DISPL. TO VENT)

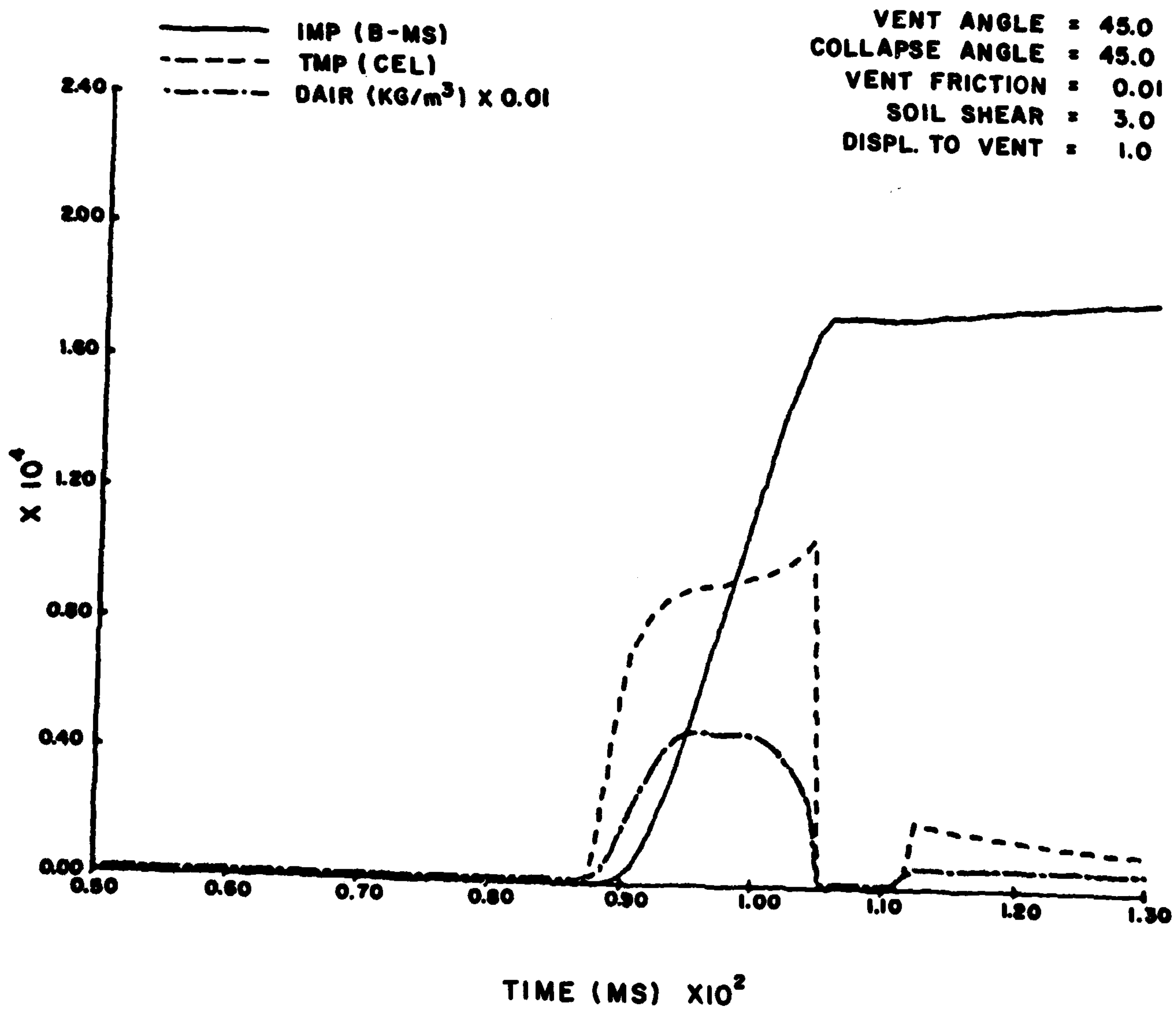


FIG. A-7b VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (1m DISPL. TO VENT)

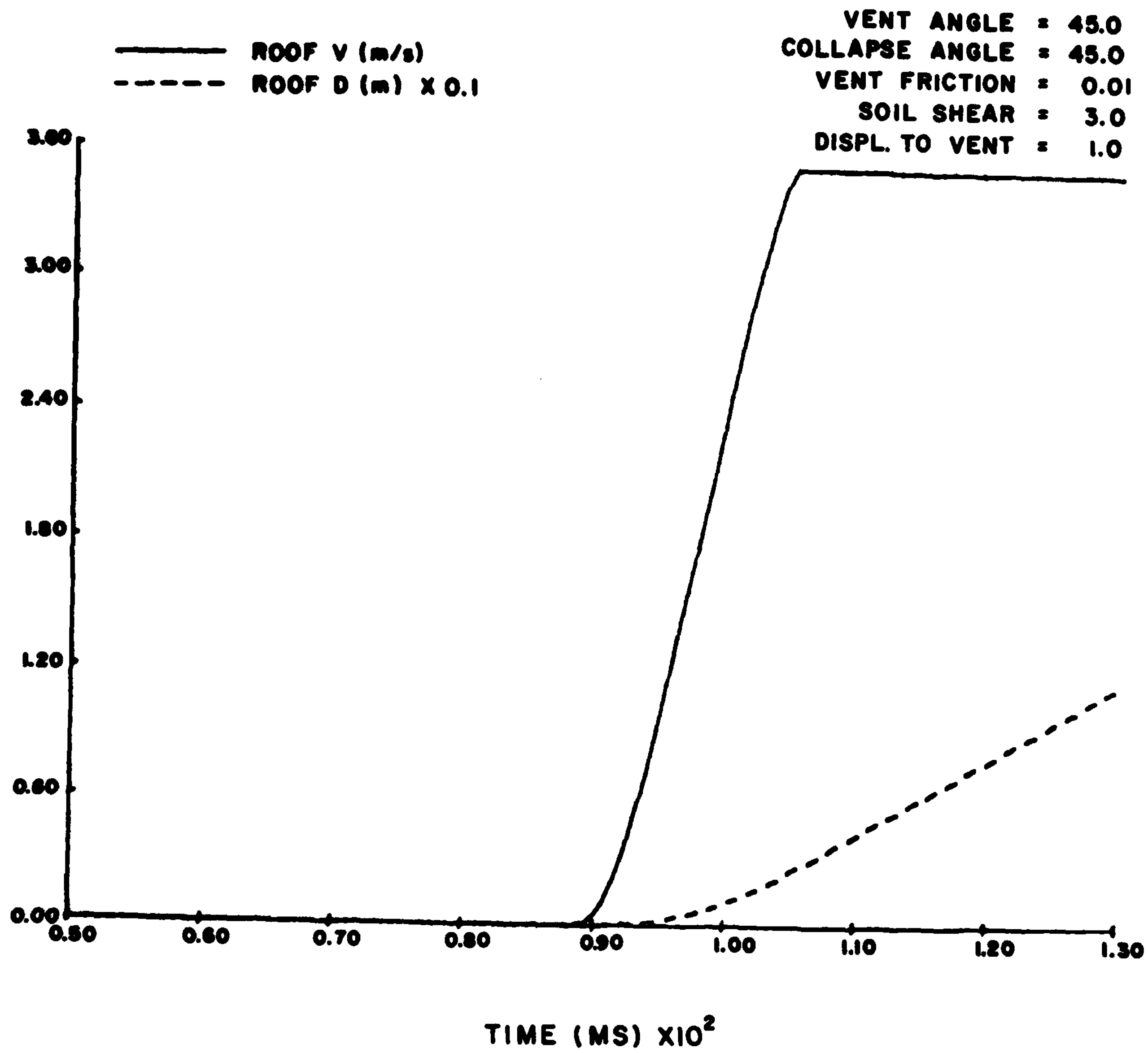


FIG. A-7c VENTING ANALYSIS-S^3 EXPANSION ABLATION INPUT (1m DISPL. TO VENT)

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